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SOME MEASUREMENTS OF BUFFETING ENCOUNTERED BY A DOUGLAS D-558-II RESEARCH AIRPLANE IN THE MACH NUMBER RANGE FROM 0.5 TO 0.95

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SOME MEASUREMENTS OF BUFFETING ENCOUNTERED BY A DOUGLAS D-558-II RESEARCH AIRPLANE IN THE MACH NUMBER RANGE FROM 0.5 TO 0.95

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SUMMARY

A flight investigation of the variation of the intensity of buffeting with lift and Mach number has been conducted with a Douglas D-558-II research airplane in the Mach number range from 0.5 to 0.95 at altitudes varying from 20,000 to 35,000 feet. The values of peak airplane normal-force coefficient attained varied from about 1.0 to 1.3. Buffeting was encountered during maneuvering flight at all Mach numbers attained and during level flight at Mach numbers above 0.9. The intensity of the buffeting varied with Mach number and with airplane normal-force coefficient but, at Mach numbers greater than 0.85, lift had no appreciable effect on buffeting at normal-force coefficients less than 0.45. Measurements of the intensity of buffeting showed that, in the Mach number range from 0.5 to 0.83, low-intensity buffeting existed at normal-force coefficients about 0.1 above the buffet boundary but that, at a normal-force coefficient about 0.2 above the buffet boundary, the intensity of the buffeting was high. At Mach numbers above 0.83 high-intensity buffeting occurred at normal-force coefficients greater than 0.64 but at Mach numbers greater than 0.925, high-intensity buffeting was not experienced. The lowest normal-force coefficients at which other than low-intensity buffeting existed occurred between Mach numbers of 0.90 and 0.93.

INTRODUCTION

Buffeting may be defined as an aerodynamically induced structural vibration of one or more components of an airplane. Its origin lies in the turbulent flow existing in the wake behind a wing and in the unsteady flow associated with separation. The seriousness of buffeting lies in the possibility of structural fatigue, in the possible imposition of maneuvering limits due to the intensity of the buffeting, in pilot discomfort, and in the creation of an unsteady gun platform.

The National Advisory Committee for Aeronautics is utilizing the Douglas D-558-II research airplanes for flight investigations at the NACA High-Speed Flight Research Station at Edwards Air Force Base, Calif., as part of the cooperative NACA-Navy transonic flight research program. This paper presents some results of an investigation of the buffeting experienced by a Douglas D-558-II airplane in the Mach number range from 0.5 to 0.95.

SYMBOLS

a	velocity of sound, ft/sec
C_{N_A}	airplane normal-force coefficient, nW/qS
g	acceleration due to gravity, ft/sec^2
h_p	pressure altitude, ft
M	Mach number, V/a
n	airplane normal load factor, g units
q	free-stream dynamic pressure, $\rho V^2/2$, lb/sq ft
S	wing area, sq ft
V	free-stream velocity, ft/sec
W	airplane gross weight, lb
α	airplane angle of attack, deg
ΔC_N	incremental fluctuation of airplane normal-force coefficient due to buffeting, $W\,\Delta n/qS$
Δn	incremental fluctuation in normal acceleration due to buffeting, g units
ρ	mass density of air, slug/ft^3

AIRPLANE AND INSTRUMENTATION

The Douglas D-558-II airplanes have sweptback wing and tail surfaces and are air-launched from a modified Boeing B-29 airplane. The D-558-II airplane used for the present investigation is powered by a turbojet engine exhausting from the bottom of the fuselage ahead of the tail and by a rocket motor exhausting from the extreme rear of the fuselage. The inlet ducts for the turbojet engine are flush with the fuselage and are located ahead of and below the wing-fuselage juncture. Photographs of the airplane are shown in figure 1 and a three-view drawing is shown in figure 2. Pertinent airplane dimensions and physical characteristics are listed in table I. The airplane is equipped with an adjustable stabilizer and both leading-edge slats and stall-control fences are incorporated on the wings. The wing slats can be locked in the closed position or they can be unlocked.

Standard NACA recording instruments, synchronized by a common timer, were used to record normal acceleration, airspeed, altitude, and angle of attack. Strain-gage bridges are installed at the roots of the wing and tail to measure stress levels and steady loads. The responses of all strain gages were recorded with a Consolidated recording oscillograph at frequencies flat to 60 cycles per second. The airspeed system was calibrated at all Mach numbers by the NACA radar-phototheodolite method (ref. 1) and the accuracy of the Mach numbers presented herein is estimated as ±0.010.

TESTS AND PROCEDURE

The data presented herein were obtained during turns at altitudes varying from 20,000 to 35,000 feet. All data were taken with the airplane in the clean (slats-locked-closed) condition. The position of the stabilizer was not varied during the turns. For these tests, both the rocket motor and the turbojet engine were used for climb to altitude and for acceleration to low supersonic speeds. Most of the data were taken after the exhaustion of rocket fuel when the airplane was powered by the turbojet engine only. Neither the presence nor type of power has been found to have any significant effect on the data taken.

During buffeting one or all of the major components of the airplane vibrate structurally. The acceleration at the center of gravity of the airplane due to structural vibrations of the components is a criterion of buffeting of the airplane as an entity. The buffet intensities presented in this paper were determined by measuring the amplitudes of buffet-induced fluctuations in normal acceleration and converting these incremental accelerations to values of incremental normal-force coefficient ΔC_N. Preliminary unpublished data obtained with another research airplane have indicated that, in the altitude range from 15,000 to 35,000 feet, altitude or dynamic pressure appeared to have no substantial effect on the intensity of buffeting when expressed in coefficient form. Accordingly, the variations in altitude during the present tests are not considered to affect appreciably the buffet-intensity data presented herein.

The accelerometer used for buffet-intensity determination was located near the center of gravity of the airplane. It is an air-damped instrument having a natural frequency of 13.5 cycles per second. The response of this instrument varies with air density and forcing frequency. The incremental-acceleration data obtained with it have been corrected for both variants by using the predominant buffet frequency (12.5 cps) as the forcing frequency. It is realized that the use of a low natural-frequency air-damped accelerometer in evaluating buffet-induced accelerations (or incremental normal-force coefficients) is somewhat questionable; however, in the interest of providing some information on buffeting as soon as possible, the data obtained with available instrumentation were reduced, corrected insofar as possible, and are presented in this paper. The strain gages installed at the roots of the wing and tail could not be used to determine the magnitudes of buffet loads.

RESULTS AND DISCUSSION

A typical example of the relationship among lift, angle of attack, and buffeting is shown in figure 3 where the buffet-induced fluctuation in normal-force coefficient ΔC_N about the mean airplane normal-force coefficient C_{N_A} is presented as a function of angle of attack for a Mach number of approximately 0.8. As is shown, steady lift exists up to an angle of attack of about 3° but, as angle of attack is further increased, buffeting starts and increases in intensity up to a peak ΔC_N of ± 0.075 at an angle of attack of 8°. It should be noted that the normal-force curve rapidly decreases in slope between angles of attack of 6° and 8° and that the decrease in slope is accompanied by a rapid increase in the intensity of the buffeting. The decrease in the intensity of buffeting which occurs at an angle of attack of about 10° is possibly the result of a high rate of change of angle of attack but the relation between rate of pitch and buffeting intensity has not been investigated.

Values of ΔC_N less than ± 0.02 have been arbitrarily considered to represent low-intensity buffeting. High-intensity buffeting has been arbitrarily considered to be equivalent to values of ΔC_N greater than ± 0.05. When expressed in terms of incremental normal-force coefficient, buffet intensity is indicative of the relative severity of buffeting. Values of ΔC_N are expressive of actual buffet magnitude only at some given value of dynamic pressure and wing loading. The wing loadings, operational altitudes, and pilots' opinions of buffeting for several fighter-type airplanes were taken into account in the selection of ΔC_N values of ± 0.02 and ± 0.05 for low- and high-intensity buffeting. For the maneuver of figure 3, the buffeting below an angle of attack of 4.5° is of low intensity. Above an angle of attack of 7° the buffeting is of high intensity.

Buffet frequencies were determined from fluctuations in normal acceleration at the airplane center of gravity and from stress fluctuations at the roots of the wing and horizontal tail. Acceleration fluctuations were recorded predominantly at an average frequency of 12.5 cycles per second. Because of the poor frequency-response characteristics of the accelerometer, no response to frequencies higher than 12.5 cycles per second were recorded. The buffet frequencies indicated by wing and tail stress fluctuations are presented in table II. Although no quantitative measurements of buffet-induced stresses have been made, the relative amplitudes and order of occurrence of stress fluctuations are included in the table as a matter of interest. In general, the higher frequencies were found to be superimposed on the lower frequency fluctuations. The correlation between natural structural frequencies and buffet frequencies is shown in table III. The natural structural frequencies were determined by ground vibration tests (ref. 2).

The variation of airplane buffet intensity with airplane normal-force coefficient at Mach numbers of approximately 0.5, 0.8, and 0.9 is presented in figure 4. At Mach number of 0.5 and 0.8 (figs. 4(a) and 4(b), respectively), the start of buffeting is a clearly defined point. At a Mach number of approximately 0.9 (fig. 4(c)) buffeting was present at the lowest normal-force coefficient attained. The variation with Mach number of the onset of buffeting during the present tests is shown in figure 5. The buffet boundary established during previous low-altitude flights of the airplane (ref. 3) is also shown in the figure. Most of the data of the present investigation are in fair agreement with the buffet boundary previously established. The buffet-boundary point shown at $C_{N_A} = 0.09$ and $M = 0.872$ occurred at an altitude of 20,000 feet, the approximate altitude of the tests of reference 3, but the remainder of the buffet-boundary points at Mach numbers greater than 0.85 were obtained at altitudes in excess of 30,000 feet and indicate that, at that altitude, buffeting starts at a slightly higher Mach number. The data are not sufficient, however, to establish conclusively that the onset of buffeting does vary with altitude.

The intensity of buffeting does not increase with lift immediately after its onset. The point at which there is an abrupt increase in buffet intensity with increase in lift is termed the buffet-intensity rise. Buffet-intensity-rise points are indicated in figure 4. The variation of the buffet-intensity rise with Mach number is shown in figure 5. The intensity-rise boundary denotes the depth to which the buffet region can be penetrated before buffeting of increasing severity is experienced. It may be seen in figure 5 that the increment in normal-force coefficient between the buffet boundary and the intensity-rise boundary is not appreciable for this airplane at Mach numbers less than 0.85 but, at Mach numbers greater than 0.85, lift has no appreciable effect on buffeting at normal-force coefficients less than $C_{N_A} \approx 0.45$ although buffeting exists at normal-force coefficients less than 0.1. The boundary for a decay in longitudinal stability of the airplane (ref. 4) is included in figure 5 as a matter of interest. It may be noted that at Mach numbers less than 0.9, the buffet intensity occurs at a lower normal-force coefficient than the decay in longitudinal stability.

The variation of the intensity of buffeting with normal-force coefficient is somewhat random during any one maneuver. This is indicated by the data of figure 4. However, it has been found that, in general, the maximum buffet intensities that will be encountered at any given value of lift fall within an envelope described about the intensities measured during any one maneuver. Plots similar to those of figure 4 have been made for every turn in which buffeting was encountered and the buffet intensities determined from faired envelopes of the data are summarized in figure 6. For the Mach number range from 0.5 to 0.83 it can be seen that, at normal-force coefficients about 0.1 above the buffet boundary, the intensity of the buffeting is low but that, at an increment in C_{N_A} of about 0.2 above the buffet boundary, high-intensity buffeting is encountered. As Mach number increased from 0.83, the normal-force coefficients defining the buffet boundary decreased rapidly but the normal-force coefficients defining the upper limit of low-intensity buffeting decreased very gradually to a minimum value of 0.4 and then increased as Mach number increased from 0.93. High-intensity buffeting occurred at normal-force coefficients greater than 0.64 but at Mach numbers greater than 0.925, high-intensity buffeting was not experienced. It is of some importance to note that the lowest normal-force coefficients at which the various buffet intensities exist occur between Mach numbers of 0.90 and 0.93. Further increase in Mach number at constant lift results in a decrease in the intensity of buffeting. Buffet intensities greater than $\Delta C_N = \pm 0.05$ could not be summarized because of insufficient data; however, as is shown in figure 4, buffet intensities much greater than $\Delta C_N = \pm 0.05$ were encountered at high values of airplane normal-force coefficient. The peak airplane normal-force coefficients shown in figure 6 are the highest values which have been attained. Maximum normal-force coefficient, as evidenced by a decrease in normal-force coefficient with increase in angle of attack, has not been attained. The variation of buffet intensity with Mach number and lift as determined in the present tests is compared in figure 7 with similar data obtained at high subsonic and supersonic speeds with an all-rocket version of the Douglas D-558-II (ref. 5). The all-rocket D-558-II airplane is identical in configuration to the dual-powered airplane used in the present investigation except that it has no turbojet engine and inlet and exhaust ducts have been eliminated. The discrepancies in the variation of buffet intensity that exist between the two airplanes are attributed mainly to the limited data from which the results were obtained and to inaccuracies in Mach number. Altitude effects, if any, could not be determined.

Comparison of the subsonic and supersonic buffet regions of figure 7 shows that, at Mach numbers less than 0.95, buffeting is much more serious than at higher Mach numbers. Transition from subsonic to supersonic flight can be accomplished without experiencing other than low-intensity buffeting if a normal-force coefficient of 0.4 is not exceeded but the onset of high-intensity buffeting at moderate values of normal-force coefficient establishes a limitation on the maneuverability of the airplane at Mach numbers less than 0.925. It must be realized, however, that large loss of Mach number can occur during high subsonic and supersonic maneuvers because of high drag due to lift. Loss in Mach number at high lift above $M = 0.925$ results in the airplane abruptly entering the region of high-intensity buffeting.

As a matter of interest, the variation with Mach number of the normal-force coefficient produced by constant angles of attack is presented in figure 8. Data from both the dual-powered airplane of the present tests and the all-rocket airplane are contained in the figure and appear to be in good agreement. In figure 9 the buffet boundary and the various buffet-intensity limits have been superimposed on the curves of constant angle of attack presented in figure 8. For the sake of clarity, discrepancies in the buffet-intensity limits have been faired out by assuming that, in general, the data of the present tests are the more accurate. No additional discussion of the variation of the buffet intensities is thought necessary but it should be observed that, for normal-force coefficients at which high-intensity buffeting occurs, the increment in normal force produced by incremental increase in angle of attack is very small. Thus, the onset of high-intensity buffeting can be considered the practical maneuvering limit of the airplane.

CONCLUDING REMARKS

A flight investigation of the variation of the intensity of buffeting with lift and Mach number has been conducted with a Douglas D-558-II research airplane in the Mach number range from 0.5 to 0.95 at altitudes varying from 20,000 to 35,000 feet. The values of peak airplane normal-force coefficient attained varied from about 1.0 to 1.3. Buffeting was encountered during maneuvering flight at all Mach numbers attained and during level flight at Mach numbers above 0.9. The intensity of the buffeting varied with Mach number and with airplane normal-force coefficient but, at Mach numbers greater than 0.85, lift had no appreciable effect on buffeting at normal-force coefficients less than 0.45. Measurements of the intensity of buffeting showed that, in the Mach number range from 0.5 to 0.83, low-intensity buffeting existed at normal-force coefficients about 0.1 above the buffet boundary but that at a normal-force coefficient about 0.2 above the buffet boundary, the intensity of the buffeting was high. At Mach numbers above 0.83, high-intensity buffeting occurred at normal-force coefficients greater than 0.64 but, at Mach numbers greater than 0.925, high-intensity buffeting was not experienced. The lowest normal-force coefficients at which other than low-intensity buffeting existed occurred between Mach numbers of 0.90 and 0.93.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 2, 1953.

REFERENCES

1. Zalovcik, John A.: A Radar Method of Calibrating Airspeed Installations on Airplanes in Maneuvers at High Altitudes and at Transonic and Supersonic Speeds. NACA Rep. 985, 1950. (Supersedes NACA TN 1979.)

2. Anon.: Final Ground Vibration Tests, Model D-558-II. Rep. No. ES 21057, Douglas Aircraft Co., Inc., Feb. 1948.

3. Mayer, John P., and Valentine, George M.: Flight Measurements With the Douglas D-558-II (BuAero No. 37974) Research Airplane. Measurements of the Buffet Boundary and Peak Airplane Normal-Force Coefficients at Mach Numbers up to 0.90. NACA RM L50E31, 1950.

4. Fischel, Jack, and Nugent, Jack: Flight Determination of the Longitudinal Stability in Accelerated Maneuvers at Transonic Speeds for the Douglas D-558-II Research Airplane Including the Effects of an Outboard Wing Fence. NACA RM L53A16, 1953.

5. Baker, Thomas F.: Some Measurements of the Buffet Region of a Swept-Wing Research Airplane During Flights to Supersonic Mach Numbers. NACA RM L53D06, 1953.

TABLE I

PHYSICAL CHARACTERISTICS OF THE DOUGLAS D-558-II AIRPLANE

Wing:	
Root airfoil section (normal to 0.30 chord)	NACA 63-010
Tip airfoil section (normal to 0.30 chord)	NACA 63_1-012
Total area, sq ft	175.0
Span, ft	25.0
Mean aerodynamic chord, in.	87.301
Root chord (parallel to plane of symmetry), in.	108.91
Tip chord (parallel to plane of symmetry), in.	61.18
Taper ratio	0.565
Aspect ratio	3.570
Sweep at 0.30 chord, deg	35.0
Incidence at fuselage center line, deg	3.0
Dihedral, deg	-3.0
Geometric twist, deg	0
Total aileron area (rearward of hinge), sq ft	9.8
Aileron travel (each), deg	± 15
Total flap area, sq ft	12.58
Flap travel, deg	50
Horizontal tail:	
Root airfoil section (normal to 0.30 chord)	NACA 63-010
Tip airfoil section (normal to 0.30 chord)	NACA 63-010
Area (including fuselage), sq ft	39.9
Span, in.	143.6
Mean aerodynamic chord, in.	41.75
Root chord (parallel to plane of symmetry), in.	53.6
Tip chord (parallel to plane of symmetry), in.	26.8
Taper ratio	0.50
Aspect ratio	3.59
Sweep at 0.30 chord line, deg	40.0
Dihedral, deg	0
Elevator area, sq ft	9.4
Elevator travel, deg	
Up	25
Down	15
Stabilizer travel, deg	
Leading edge up	4
Leading edge down	5

TABLE I - Concluded

PHYSICAL CHARACTERISTICS OF THE DOUGLAS D-558-II AIRPLANE

Vertical tail:	
Airfoil section (normal to 0.30 chord)	NACA 63-010
Area, sq ft	36.6
Height from fuselage center line, in.	98.0
Root chord (parallel to fuselage center line), in.	146.0
Tip chord (parallel to fuselage center line), in.	44.0
Sweep angle at 0.30 chord, deg	49.0
Rudder area (rearward of hinge line), sq ft	6.15
Rudder travel, deg	±25
Fuselage:	
Length, ft	42.0
Maximum diameter, in.	60.0
Fineness ratio	8.40
Speed-retarder area, sq ft	5.25
Engines:	
Turbojet	J-34-WE-40
Rocket	LR8-RM-6
Airplane weight, lb:	
Full jet and rocket fuel	15,131
Full jet fuel	11,942
No fuel	10,382
Center-of-gravity locations, percent M.A.C.:	
Full jet and rocket fuel (gear up)	23.5
Full jet fuel (gear up)	25.2
No fuel (gear up)	27.0
No fuel (gear down)	26.4

TABLE II

BUFFET FREQUENCIES OF WING AND TAIL OF DOUGLAS D-558-II AIRPLANE

Component	Frequency, cps	Relative occurrence	Relative amplitude
Wing	11.8 to 14.0	Predominant	Large
	14.0 to 17.0	Intermittent	Moderate
	20.5 to 23.5	Infrequent	Small
	42.0 to 48.0	Predominant	Moderate
Tail	7.9 to 11.0	Intermittent	Moderate
	12.2 to 16.1	Predominant	Large
	21.0 to 27.6	Intermittent	Small
	34.0 to 38.6	Infrequent	Small
	Greater than 50	Infrequent	Very small

TABLE III

CORRELATION BETWEEN NATURAL AND BUFFET FREQUENCIES FOR DOUGLAS D-558-II AIRPLANE

Natural structural frequencies			Buffet frequencies	
Component	Mode	Frequency, cps	Frequency, cps	Component
Wing	Bending			
	First symmetrical (A)	12.5	11.8 to 14.0	Wing
	First symmetrical (B)	15.3	14.0 to 17.0	Wing
			12.2 to 16.1	Horizontal stabilizer
	First unsymmetrical	22.5	20.5 to 23.5	Wing
			21.0 to 27.6	Horizontal stabilizer
	Torsion			
	First symmetrical	43.5	42.0 to 48.0	Wing
	First unsymmetrical	44.4		
Horizontal stabilizer	Rocking	7.8	7.9 to 11.0	Horizontal stabilizer
	Bending			
	First unsymmetrical	25.0	21.0 to 27.6	Horizontal stabilizer
Fuselage	Torsion	27.8	21.0 to 27.6	Horizontal stabilizer
Vertical stabilizer	Bending	36.1	34.0 to 38.6	Horizontal stabilizer
Airplane	Mode I	12.3	11.8 to 14.0	Wing
	Mode II	15.7	14.0 to 17.0	Wing
			12.2 to 16.1	Horizontal stabilizer

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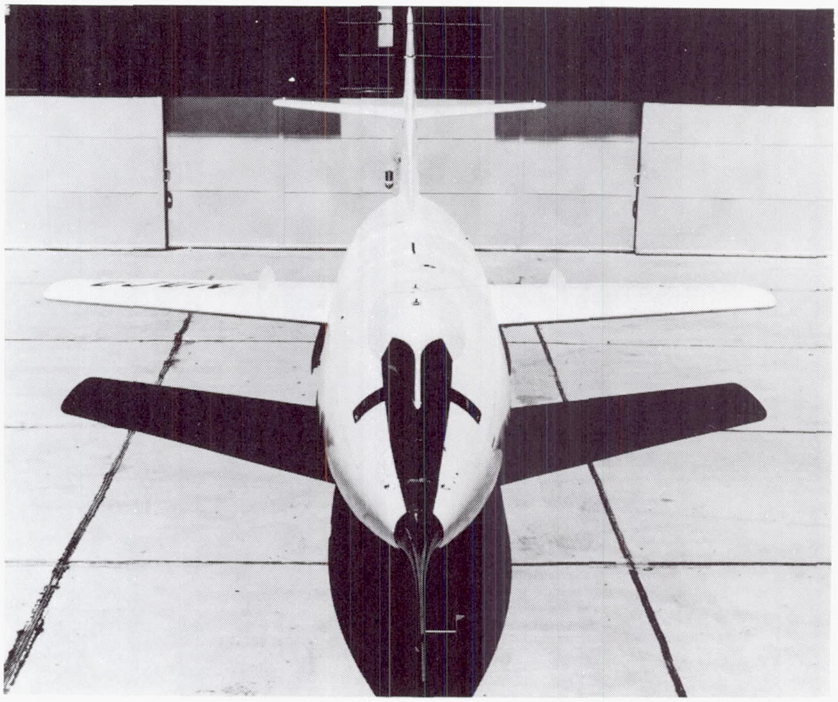

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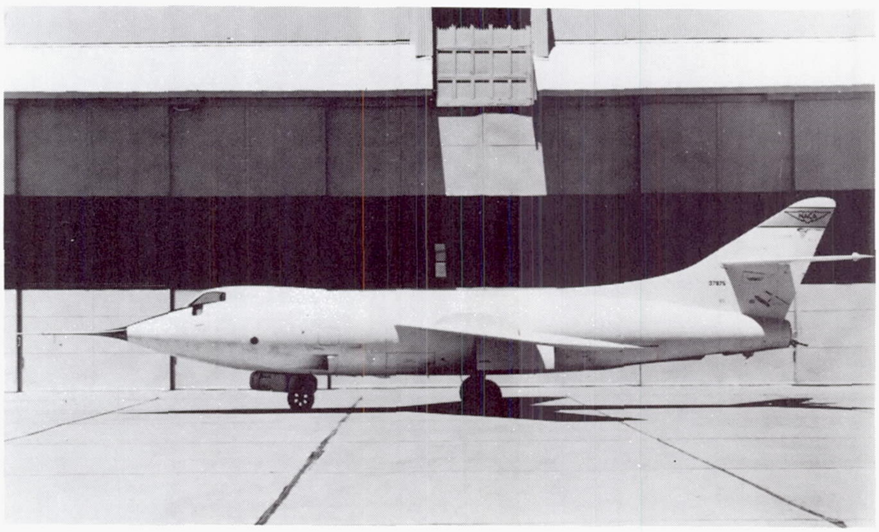
(a) Front overhead view of the dual-powered Douglas D-558-II research airplane.



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(b) Side view of the dual-powered Douglas D-558-II research airplane.

Figure 1.- Photographs of Douglas D-558-II research airplane powered by both a turbojet engine and a rocket motor.

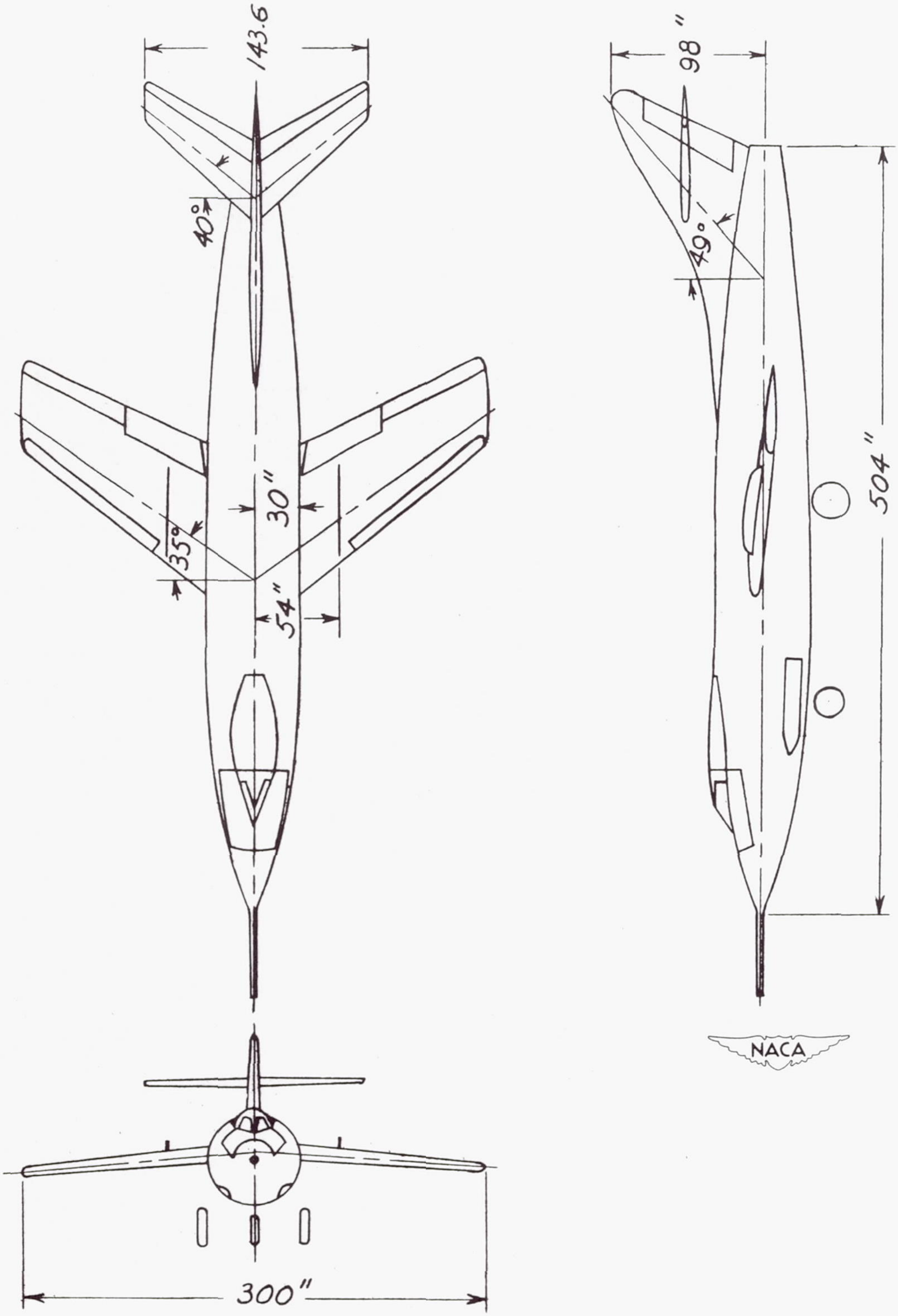

Figure 2.- Three-view drawing of the dual-powered Douglas D-558-II research airplane.

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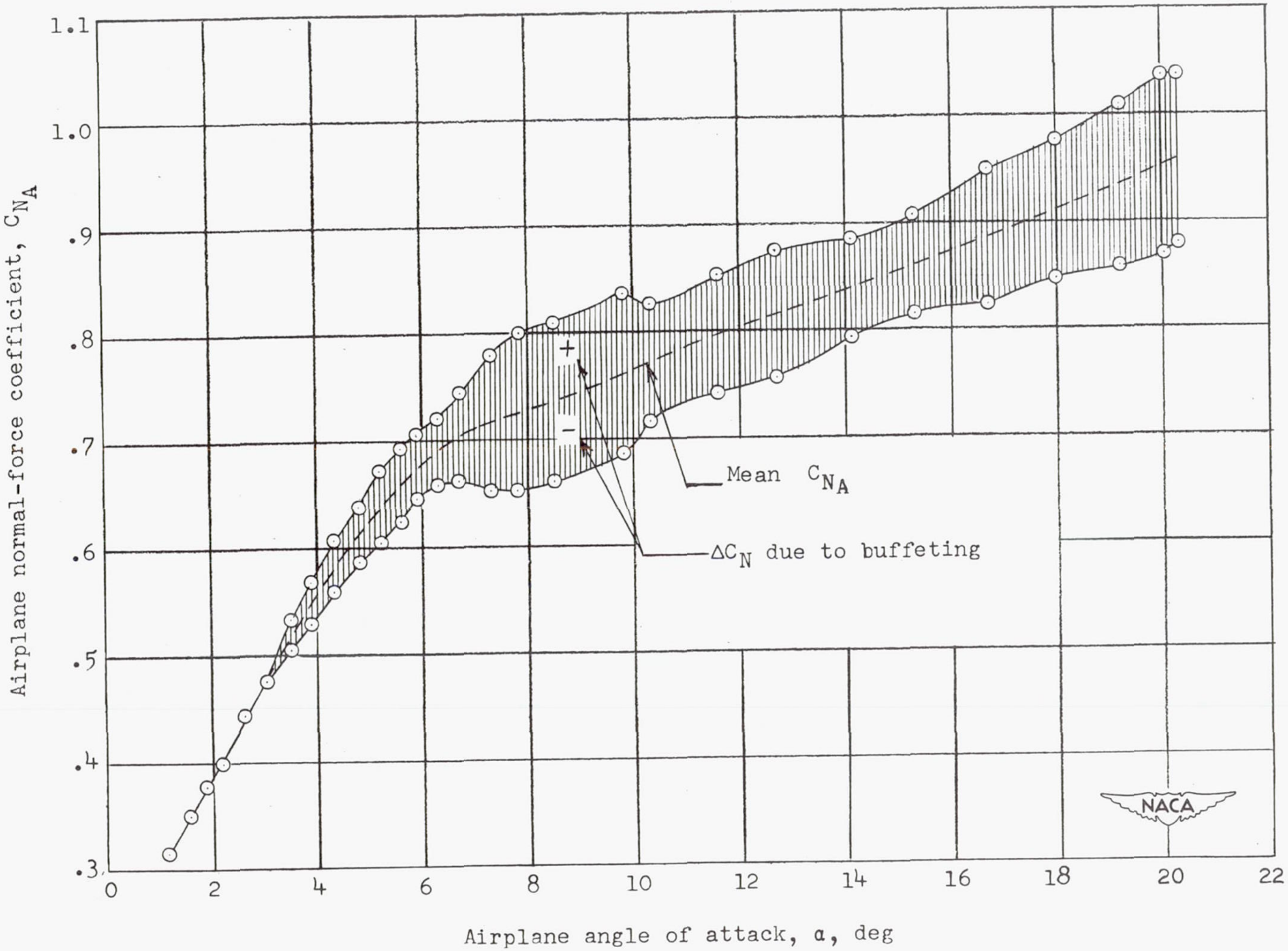

Figure 3.- Variation with airplane angle of attack of the mean airplane normal-force coefficient and the increment in normal-force coefficient caused by buffeting. Wind-up turn; $M \approx 0.80$; $h_p \approx 25{,}000$ feet.

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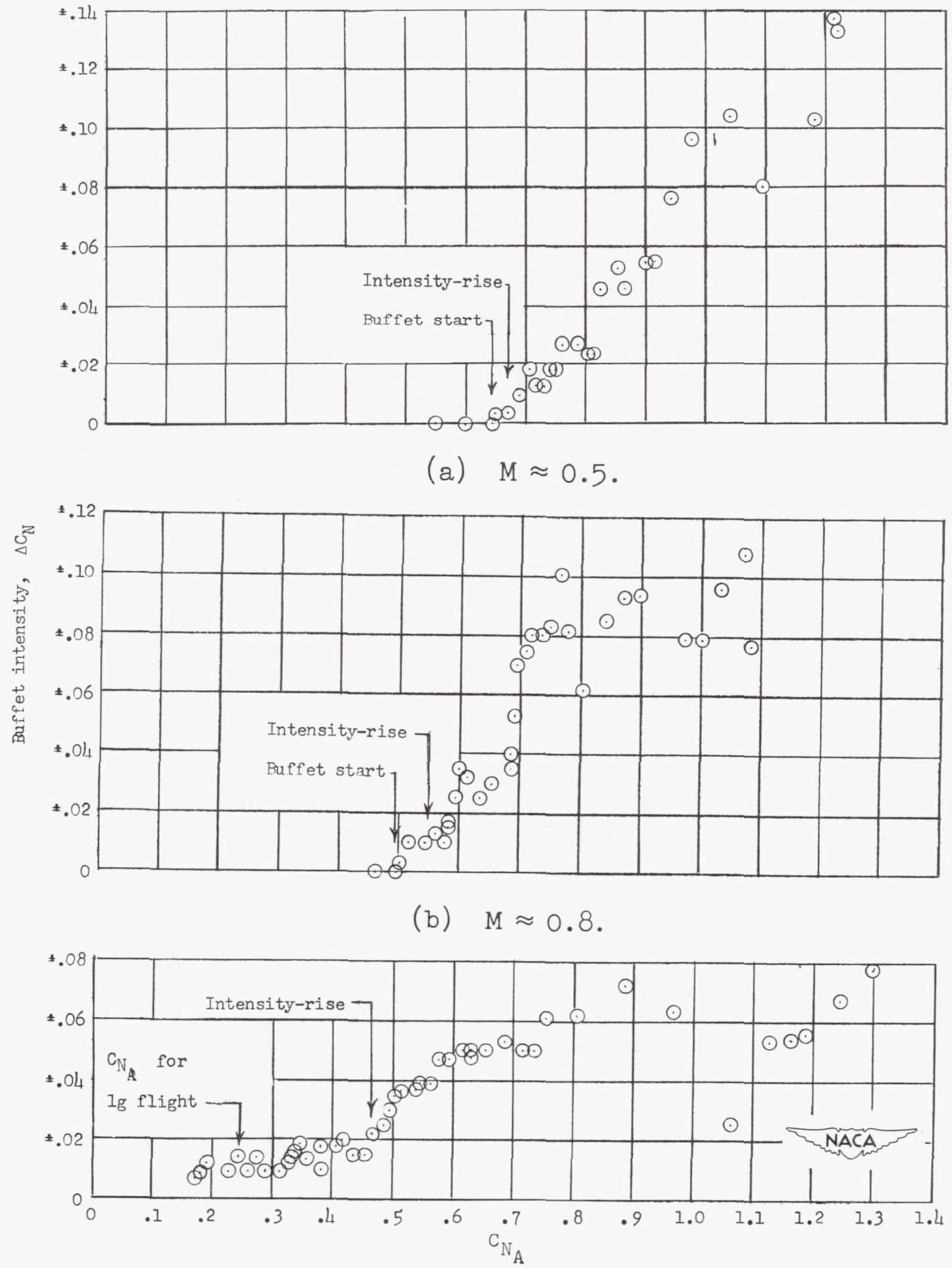

(c) M ≈ 0.9.

Figure 4.- Variation of buffet intensity with airplane normal-force coefficient at Mach numbers of approximately 0.5, 0.8, and 0.9. $h_p \approx$ 25,000 to 35,000 feet.

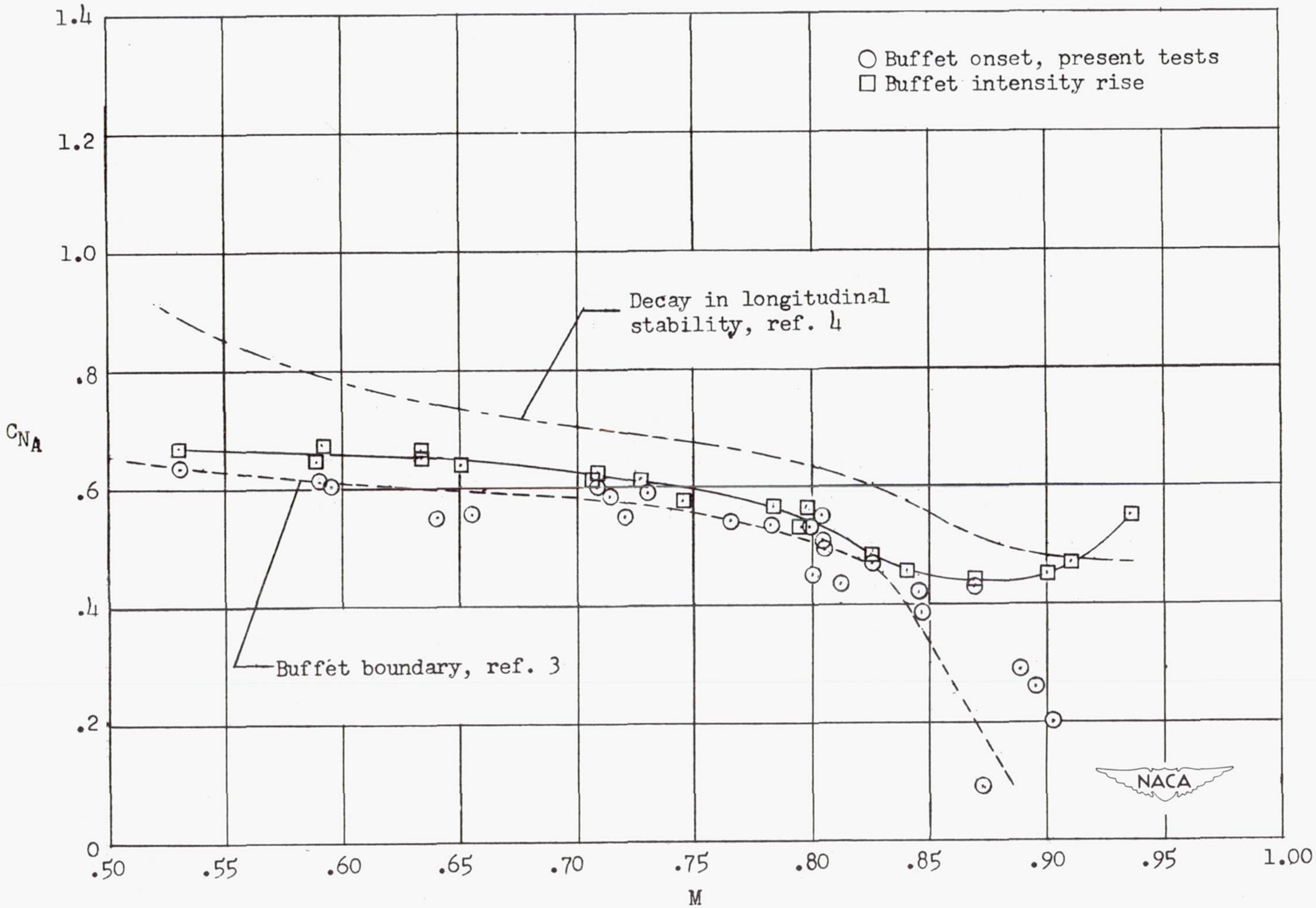

Figure 5.- The boundaries for the onset of buffeting, buffet-intensity rise, and decay in longitudinal stability for the Douglas D-558-II airplane.

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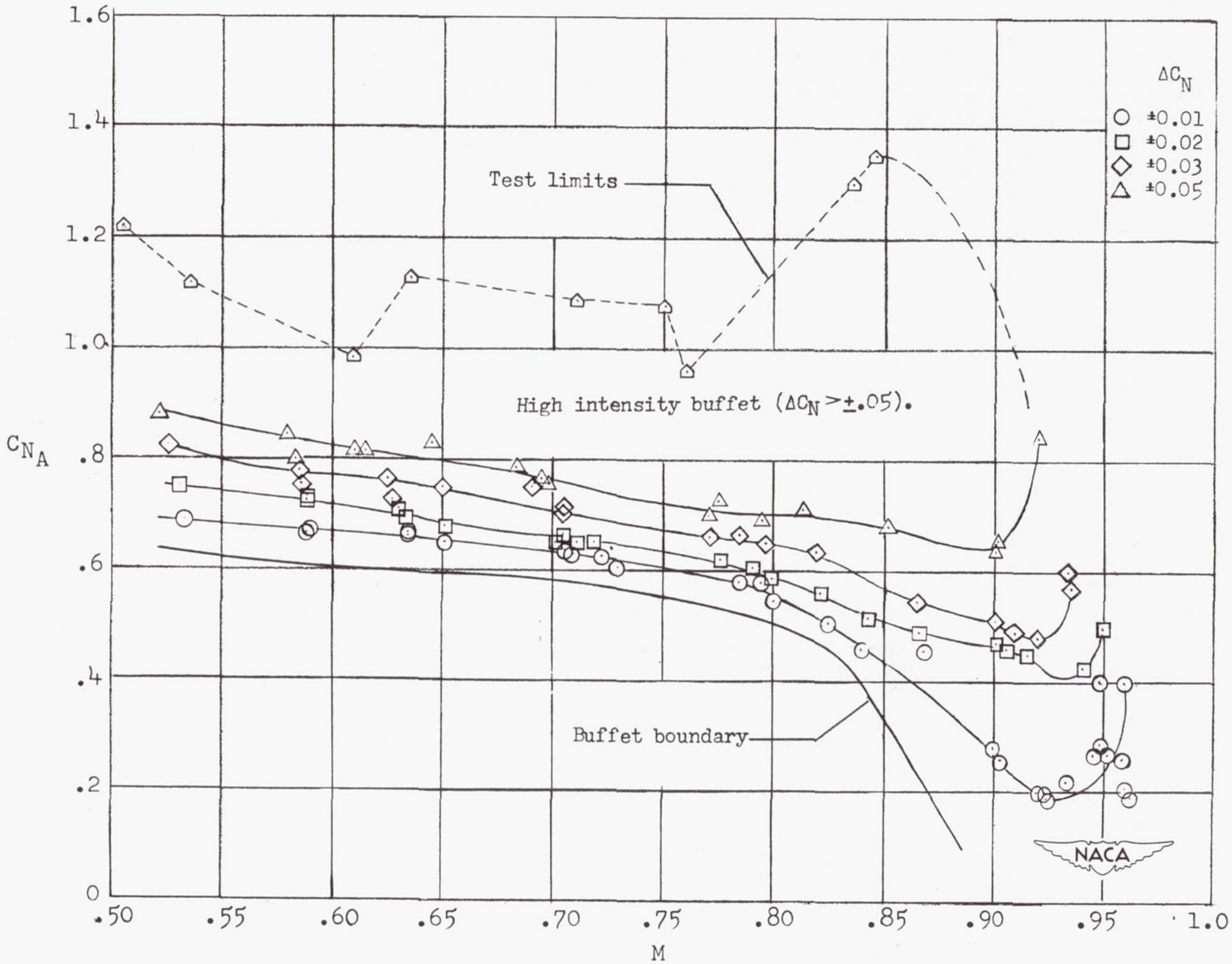

Figure 6.- The variation with Mach number and normal-force coefficient of the intensity of buffeting experienced by the dual-powered Douglas D-558-II airplane at altitudes varying from 25,000 to 35,000 feet.

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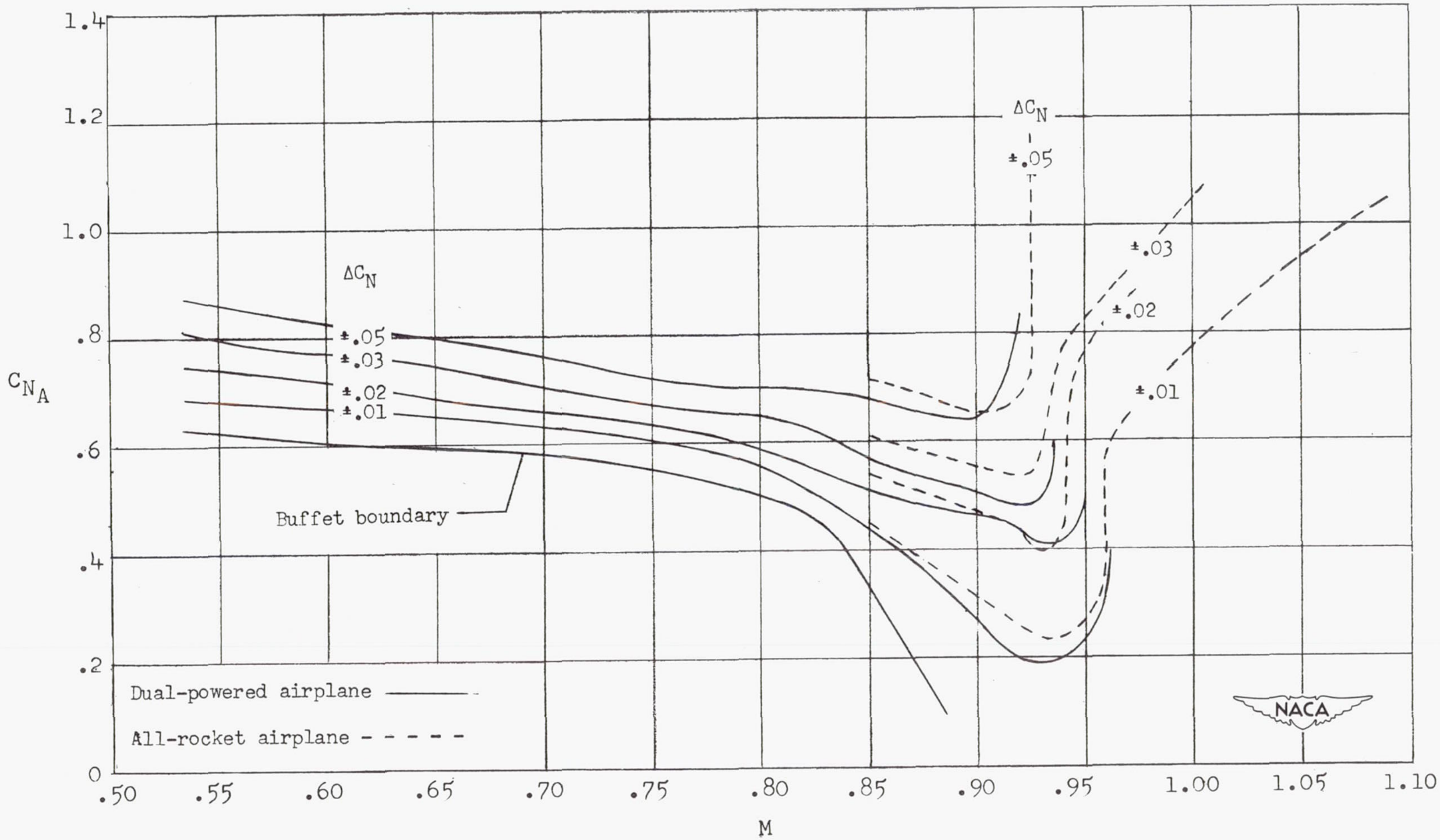

Figure 7.- Comparison of buffet-intensity limits determined with the dual-powered Douglas D-558-II airplane with similar data measured with the all-rocket Douglas D-558-II airplane.

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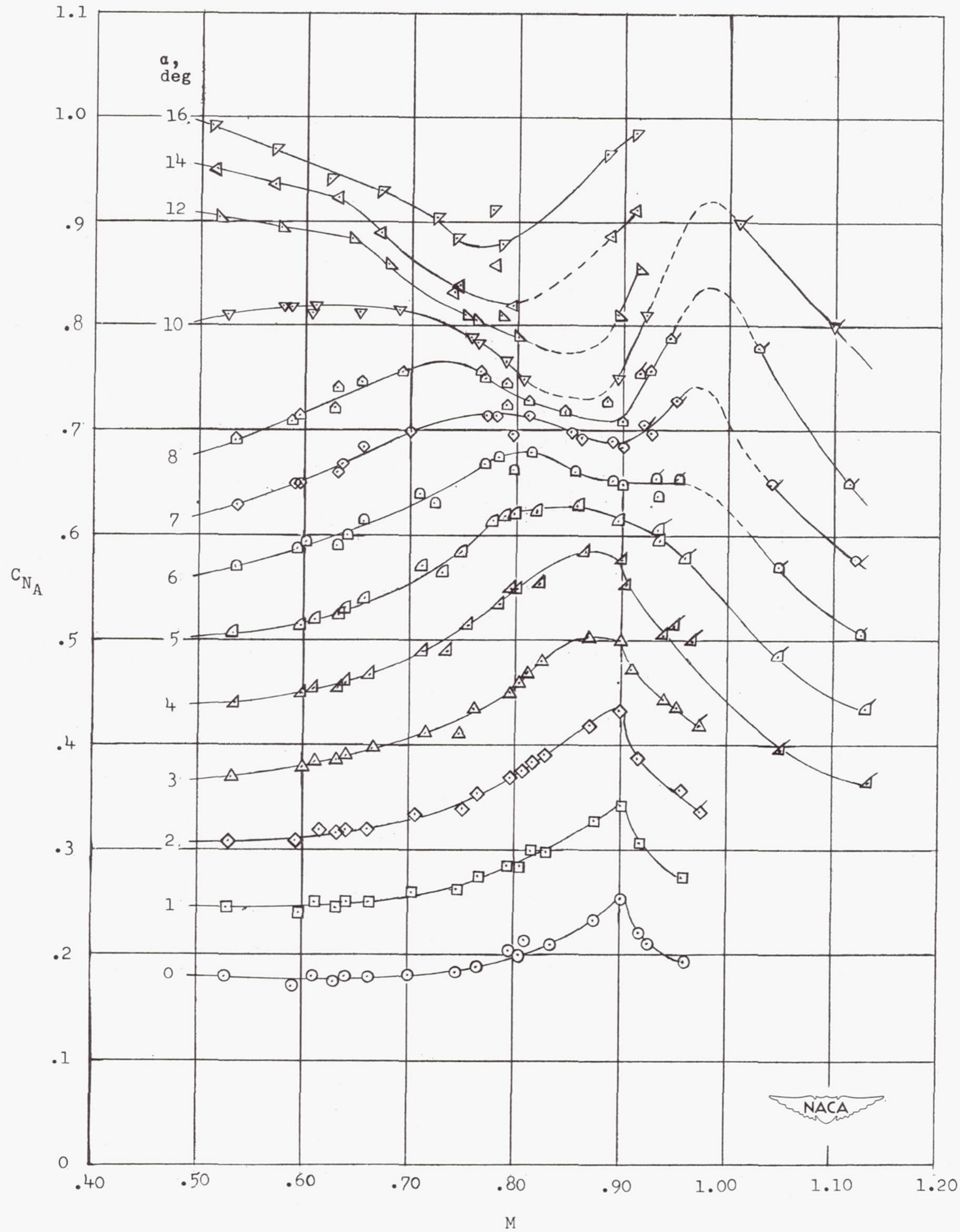

Figure 8.- The variation with Mach number of the airplane normal-force coefficients produced by constant angles of attack. Flagged symbols denote data from all-rocket Douglas D-558-II research airplane.

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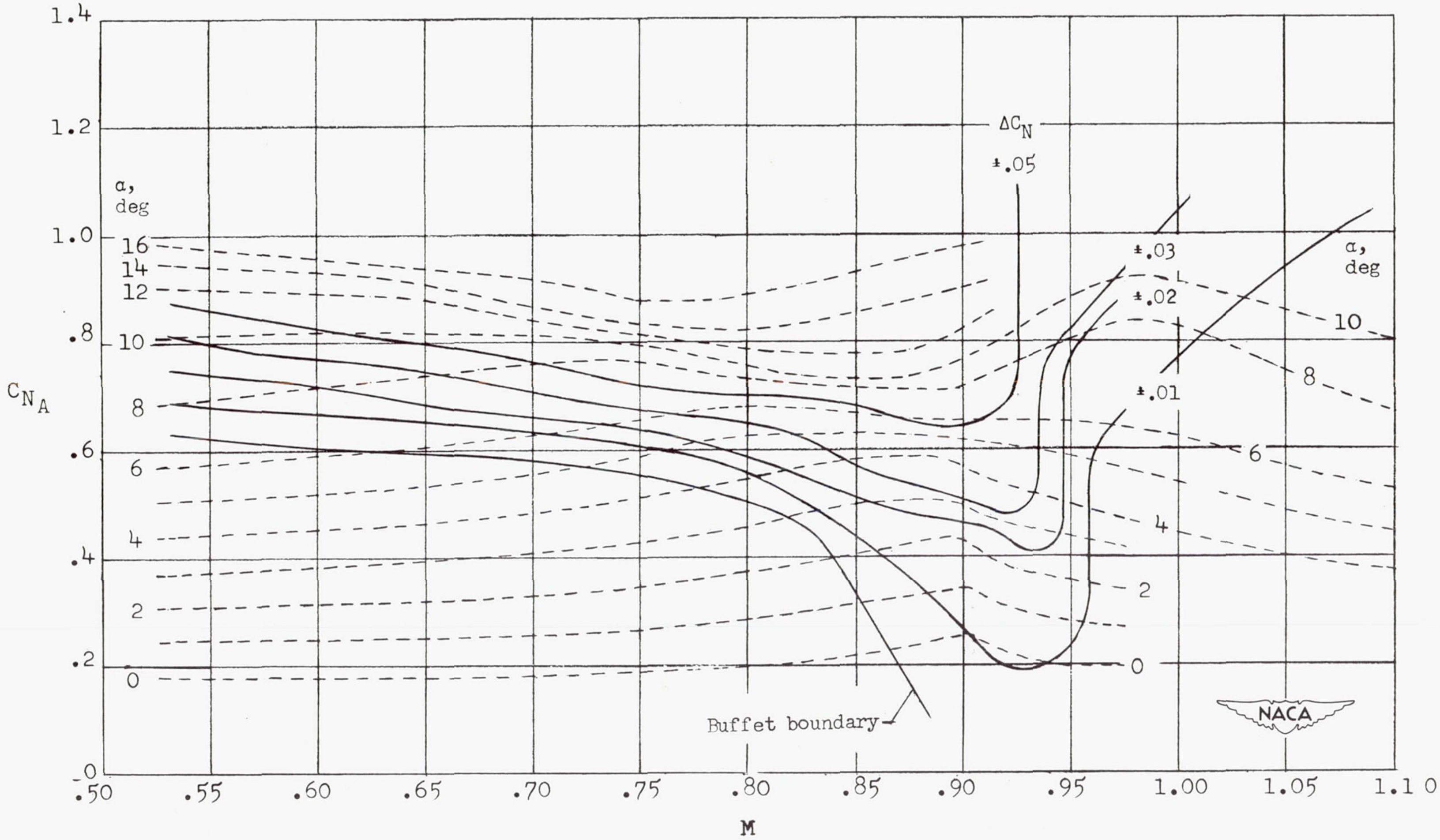

Figure 9.- Comparison with angle of attack variation, of the variation of the intensity of buffeting experienced by the Douglas D-558-II airplane.

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